Dynamic Predictive Simulations of Agent Swarms

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Contract/Grant Title: Dynamic Predictive Simulations of Agent Swarms (DDDAS)
Contract/Grant #: AFOSR FA9550-11-1-0351
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DDDAS Accomplishments: Multiple separate but related projects investigated the DDDAS paradigm applied to UAV swarms. Each project provided methods and examples of how the DDDAS concept could be used for the command and control of swarms of UAVs. As the numbers of UAVs in the military inventory increase operator shortage & overload is becoming a problem; groups or swarms of semi-autonomous UAVs will need to be controlled by the operators, requiring new modes of command & control. Operators will need to "fly the swarm" rather than a "UAV" as is largely done today.

A DDDAS test-bed was developed utilizing web-services middleware to communicate between a "real-world" UAV swarms and agent-based simulations. Six Parrot AR.Drones 2.0 quadrocopters were demo'ed as a "real world" UAV swarm communicating over the test-bed to a ground-based command & control application. Experiments were run testing the effects of intra-swarm communication protocols on target discovery.

A second investigation examined dynamic mission scheduling for swarms by incorporating DDDAS into a global-local hybrid-planning scheme. A global agent utilized simulation to determine optimal task assignment, while agents locally determine the execution order for assigned tasks.

A third project explored DDDAS in the swarm engineering context. Building upon previous work in swarm robotics, a new agent behavior for swarm search was added to introduce optimal swarm formation assignment. An agent-based simulation was developed for incorporation into a DDDAS framework for dynamic formation assignment.

A fourth investigation applied the DDDAS paradigm to two swarm command and control scenarios. In both scenarios, UAV swarms were augmented with mission-specific sensors, providing real-time measurements to a ground operator. Based on real-time measurements, the operator could adjust a single, global swarm parameter to achieve mission objectives. Together, these four projects further the DDDAS paradigm by incorporating simulations into real-time command and control of UAV swarms.

A fifth ongoing investigation is quantifying swarm performance with agent-based modeling. The modeling is demonstrating the utility of an explanatory model in the DDDAS framework, and provided an interesting juxtaposition of a bottom-up model

analyzed by a top-down clustering algorithm, where both calculated results based on the distance of agent neighbors.

A sixth ongoing investigation is extending the test-bed to incorporate enhanced UAV and remote control technology to test more realistic UAV swarms. This activity is funded in part by an AFSOR DURIP.

Archival publications derived from the project:

1) McCune, R. R., and G. R. Madey. "Swarm Control with Agent-based Simulation", *JASSS,* 2014 (in press).

2) McCune, R. R., and G. R. Madey. "Control of Artificial Swarms with DDDAS", *ICCS 2014*, Cairns, Australia, June 10-12, 2014.

3) McCune, R. R. and G. R. Madey. "Decentralized K-Means Clustering with MANET Swarms", *ADS'14/SpringSim 2014,* SCS, Tampa, FL. April 13-16, 2014

4) Madey, A., "Unmanned Aerial Vehicle Swarms: The Design and Evaluation of Command and Control Strategies using Agent-based Modeling", *IJATS*, 2014 (in press).

5) Madey, A.G., and Madey, G.R. 2013. "Design and Evaluation of UAV Swarm Command and Control Strategies," *Proceedings of the 2013 Symposium on Agent Directed Simulation (ADS'13/SpringSim 2013)*. Society for Computer Simulation International, San Diego, CA. 2013.

6) McCune, R., Y. Wei, R. Purta, A. Madey, M. B. Blake, and G. Madey, "Investigations of DDAS for Command and Control of UAV Swarms with Agent-Based Modeling." *Winter Simulation Conference 2013*. Washington D.C. December 8-11, 2013.

7) P. Mitra and C. Poellabauer, "Opportunistic Routing in Mobile Ad-Hoc Networks", *Routing in Opportunistic Networks*, Isaac Woungang Ed., Springer, 2013.

8) McCune, Ryan and Greg Madey. "Swarm Control of UAVs for Cooperative Hunting with DDDAS." *In Proceedings of 2013 International Conference on Computational Science*, Barcelona, Spain. June 5-7, 2013.

9) McCune, R. R., and G. R. Madey. "Agent-Based Simulation of Cooperative Hunting with UAVs." *Proceedings of the 2013 Symposium on Agent Directed Simulation (ADS'13/SpringSim 2013)*. Society for Computer Simulation International, San Diego, CA. 2013.

10) Purta, Rachael, M. Dobski, A. Jaworski, and G. Madey. "A Testbed for

Investigating the UAV Swarm Command and Control Problem Using DDDAS." In *Proceedings of 2013 International Conference on Computational Science*, Barcelona, Spain. June 5-7, 2013.

11) Purta, Rachael, Saurabh Nagrecha, and Gregory Madey. "Multi-hop Communications in a Swarm of UAVs." *Proceedings of the 2013 Symposium on Agent Directed Simulation (ADS'13/SpringSim 2013).* Society for Computer Simulation International, San Diego, CA. 2013.

12) Wei, Y., Madey, G.R, and Blake, M.B. Blake. "An Operation-time Simulation Framework for UAV Swarm Configuration and Mission Planning." In *Proceedings of 2013 International Conference on Computational Science*, Barcelona, Spain. June 5-7, 2013.

13) Wei, Yi, Gregory R. Madey, and M. Brian Blake. "Agent-based Simulation for UAV Swarm Mission Planning and Execution." *Proceedings of the 2013 Symposium on Agent Directed Simulation (ADS'13/SpringSim 2013),* Society for Computer Simulation International. 2013.

14) Wei, Yi, and M. Brian Blake. "Adaptive Web Services Monitoring in Cloud Environments." *International Journal on Web Portals* (2013).

15) Y. Wei and M.B. Blake, "An Agent-based Services Framework with Adaptive Monitoring in Cloud Environments", *Proceedings of the 21st IEEE International Conference on Collaboration Technologies and Infrastructures (WETICE 2012)*, IEEE Press, Toulousse, France, June 2012 - Best Student Paper Award.

16) G. Madey, et al, Applying DDDAS Principles to Command, Control and Mission Planning for UAV Swarms, in: *Procedia Computer Science*, Vol. 9, Elsevier Ltd., 2012, pp. 1177 – 1186

Additional publications from the project:

1) McCune, R. R., "Swarm Intelligence in Mobile Agent Computing for UAV Swarms With DDDAS", *Ph.D Dissertation proposal*, University of Notre Dame, 2014.

2) McCune, R. R., and G. R. Madey. "Analysis of a Swarm Approach to Building Voronoi Diagrams", *17th Annual SwarmFest Conference*, Orlando, FL, July 8-9, 2013.

3) Y. Wei, "Monitoring, Configuration and Resource Management of Service Workflows in Virtualized Clusters and Clouds", *unpublished Ph.D Dissertation*, University of Notre Dame, 2013.

4) Project Web Site, "DDDAS-C2-UAV Swarms: Investigating the Application of DDDAS to the Command & Control of UAV Swarms", http://www3.nd.edu/~dddas/AFOSR/index.html

5) G. Madey and C. Poellabauer, "Application of DDDAS Principles to Command, Control and Mission Planning for UAV Swarms", *DDDAS AFOSR PI Meeting*, Arlington, VA, Sept 30-Oct 2, 2013.

Principle Investigators:

1) Greg Madey, Department of Computer Science and Engineering, University of Notre Dame
2) M. Brian Blake, Department of Computer Science, University of Miami
3) Christian Poellabauer, Department of Computer Science and Engineering, University of Notre Dame

Contributors to the project:

1) Mikolaj Dobski, REU Student
2) Artur Jawarski, REU Student
3) R. Ryan McCune, Graduate Student
4) Hongsheng Lu, Graduate Student
5) Alexander Madey, High School Research Experience
6) Pramita Mitra, Graduate Student
7) Radoslaw Nabrzyski, High School Research Experience
8) Saurabh Nagrecha, Graduate Student
9) Rachael Purta, Graduate Student
10) Yi David Wei, Graduate Student

Project Highlights:

Y. Wei and M.B. Blake, "An Agent-based Services Framework with Adaptive Monitoring in Cloud Environments", *WETICE 2012*, IEEE Press, Toulousse, France, June 2012 -- **Best Student Paper Award**.

International Finalist: Alexander Madey, "Design and Evaluation of UAV Swarm Command and Control Strategies", *Intel International Science and Engineering Fair*, Phoenix, Arizona, May, 2013, (Junior, Trinity School at Greenlawn, South Bend, Indiana, Teacher: Lynda Seasly)

Kathy Borlik, "Trinity student exhibits at international event", Los Angeles Times, June 9, 2013
http://www.latimes.com/topic/sbt-trinity-student-exhibits-at-international-event-20130609,0,232146.column?track=rss-topicgallery#axzz2uWNfn231

Gordy Young, "Experience Michiana - Alex Madey will discuss a student research project which was presented at the INTEL ISEF and at the international research conference", WNIT TV, June 11th, 2013
http://video.wnit.org/video/2365024421/

Complementary Funding:

AFSOR DURIP, Dynamic Data Driven Application System for Command and Control of UAV Swarms, $170,848 (C. Poellabauer and G. Madey)

Two REU students (M. Dobski and A. Jawarski) were supported by an NSF REU site grant awarded to the Center for Research Computing, University of Notre Dame.

Continuing Work:

G. Madey and R. R. McCune will host the *18th Annual SwarmFest Conference*, at the University of Notre Dame, June 30 – July 1, 2014. Our work on the application of DDDAS principles to Command, Control and Mission Planning for UAV Swarms will be included as a keynote presentation.

McCune, R. R., will continue work on his dissertation "Swarm Intelligence in Mobile Agent Computing for UAV Swarms With DDDAS", with an anticipated completion date in 2015.

Collaborative work by Vijay Gupta, Greg Madey, and Christian Poellabauer at the University of Notre Dame and Young Jun Son and Jian Liu, University of Arizona on "An adaptive distributed approach to DDDAS for surveillance missions with UAV swarms" is being planned. This activity is supported in part by the AFSOR DURIP grant awarded to C. Poellabauer and G. Madey.

G. Madey and R. R. McCune will attend and participate in the DDDAS annual workshop held in conjunction with *ICCS 2014*, Cairns, Australia, 2014.

An additional REU student supported by an NSF REU site grant awarded to the Center for Research Computing, University of Notre Dame, is anticipated for the summer of 2014.

Manuscript in preparation: "Emergent Calculus with Mobile Agent Computing and Local Algorithms for DDDAS Applications", to be submitted to *ANTS 2014 : Ninth International Conference on Swarm Intelligence*, Brussels, Belgium.

Two book chapters in preparation for DDDAS book: one on *Critical Infrastructure Systems* and another on *Mission Planning for UAV Swarms*.